# U.S. EPA / FKNMS Coral Reef Evaluation and Monitoring Project

Carl R. Beaver, Walter C. Jaap, M.K. Callahan, Jim Kidney, Stopher Slade, Selena Kupfner, and Shannon Wade (Florida Fish and Wildlife Conservation Commission/Fish and Wildlife Research Institute (FWC/FWRI), St. Petersburg, FL)
James W. Porter, Katie Sutherland and Cecilia Torres (University of Georgia, Athens, GA)
Chris Tsokos and George Yanev (University of South Florida, St. Petersburg, FL)

### *Goal*

The Coral Reef Evaluation and Monitoring Project (CREMP) is part of the Water Quality Protection Program for the Florida Keys National Marine Sanctuary (FKNMS). The goal of this project is to utilize broad spatial coverage, repeated sampling, and statistically valid findings to document status and trends of coral communities within the Sanctuary. As coral reef monitoring is integrated with the seagrass and water quality monitoring projects, the results can be used to focus research on determining causality and to fine tune and evaluate management decisions.

### *Methods*

Sampling site locations were chosen in 1994 using a stratified random sampling procedure (U.S. EPA EMAP). Forty reef sites were selected within the FKNMS and permanent station markers were installed in 1995. Annual sampling began in 1996 and has continued through 2002. Three additional sites were installed and sampled in the Dry Tortugas beginning in 1999. The project's 40 sampling sites include four hard-bottom, 11 patch, and 12 offshore shallow and 13 offshore deep reef sites. Each site is composed of two to four stations.

*Station Species Inventory (SSI)*

SSI consists of counts of stony coral species (Milleporina and Scleractinia) present in each station to provide data on stony coral species richness (S). Two observers conducted simultaneous timed (15 min.) inventories within the 22 x 2 m stations and entered the data on underwater data sheets. Each observer recorded all stony coral taxa and fire corals and enumerated long-spined urchins (*Diadema antillarum*) within the station boundaries. After recording the data, observers compared (5 min.) data underwater and confirmed species recorded by only one observer. Data sheets were verified aboard the vessel and forwarded to FWRI for data entry and processing. This method facilitates data collection with broad spatial coverage at optimal expenditure of time and labor. During the species inventory any species within a station that exhibited specific signs of either bleaching or disease (black band, white complex, and other) was documented on the data sheet.

*Videography*

All sampling through 1999 was filmed with a Sony CCD-VX3 using full automatic settings. Beginning in 2000, the project upgraded to digital video filming all sites with a SONY TRV 900. To ensure quality images, artificial lights were used when necessary. A convergent laser light system aided the videographer in maintaining the camera at a uniform distance above the reef surface (40 cm). The videographer filmed a clapperboard prior to beginning each transect. This provided a complete record of date and location of each segment recorded. Filming was conducted at a constant swim speed of about 4 m/min. yielding approximately 9,000 video frames per transect. Images for all transects were frame grabbed, and written to and archived on CD-ROM.

*Bioeroding Sponge Survey*
In 2001, the project began monitoring the abundance and percent cover of bioeroding sponge species. Bioeroding sponge data were collected at all CREMP stations. The three clionid sponge species (*Cliona delitrix*, *C. lampa*, and *C. caribboea*) recorded by CREMP are known to be aggressive coral bioeroders and over growers. Clionid sampling methodology was developed based on existing project station layout. Three 1-m-wide belt transects provided the maximum spatial coverage within each station. A 30-m survey tape marked the center of reference for each transect. A diver delineated the survey area by swimming directly above the tape holding a meter stick perpendicular to the tape and parallel to the reef surface. The location, species, and size of each clionid sponge colony were recorded. The species of stony coral affected by the clionid colony was also recorded. Area was measured by means of a 40-cm by 40-cm quadrat frame subdivided into 5-cm squares. The area occupied by the clionid colony was recorded to the nearest half square.

*Stony Coral Population Dynamics*
A quantitative survey was performed at nine sites (three in each of the Upper, Middle, and Lower Keys) to provide information on the relative abundance and size classification of individual coral colonies. These data have value for defining both recruitment and community structure. Analyses of these data included relative abundance by size for individual coral species as well as community indices such as species diversity, dominance, and evenness, as well as inferential statistical testing. At each "value-added" site, abundance and size-class distribution data were collected for all stony corals. Twenty 1-m$^2$ quadrats were surveyed within a sampling station. A 1-m$^2$ quadrat frame was placed along either side of a centerline that extended between the permanent stakes marking each site. A diver recorded the species and size classification for each species of stony coral within each quadrat. Size classifications were 0-3 cm, 3-10 cm, 10-50 cm, and >50 cm. Size was measured at the point of greatest areal coverage within a colony.

*Diseased Coral Survey (DCS)*
The DCS was designed to determine whether coral diseases significantly influence the survival of coral in the Florida Keys. This study quantified the abundance and distribution of different diseases on different species of corals. Individual colonies were assessed by annually photographing individual coral specimens at each of the 18 value-added stations in the Florida Keys CREMP. All colonies affected by either bleaching or disease within the 40-m$^2$ (2 m wide by 20 m long) transect at each station were located and photographed. A digital still camera was used to take two photographs (side view with morbid or bleached area and from above) of affected corals with a clapperboard in the field of view for metadata and scale. The precise position of each colony within a transect was recorded in order to allow its relocation during subsequent resurveying.

*Temperature Study*
Temperature data were collected to document possible trends of increasing water temperatures within FKNMS sampling sites. Small in situ temperature loggers were installed at all value-

added sites during 2002 and early 2003. These data-loggers recorded water temperature hourly and were recovered, downloaded, and re-deployed quarterly.

*Statistical Analyses*
Independent consultants conducted statistical analyses of the percent cover, species richness, and disease/condition data. The decision to reject or not to reject the null hypothesis that there was no significant difference in the data for certain years was based on the minimum detectable difference for different significance levels and powers. Combinations for significance level ($\alpha$) and power (1- $\beta$) were considered: $\alpha$ = 0.05, 1-$\beta$ = 0.75; $\alpha$ = 0.10, 1-$\beta$ = 0.75. When the one-sided alternative was tested, the above values for $\alpha$ must be divided by two. The output consisted of the minimum detectable difference for a certain pair ($\alpha$, 1-$\beta$), which was used to construct a (1-$\alpha$) % confidence interval and provided a measure of the test accuracy.

***Findings to Date***
Results are reported for the regions defined as follows: Upper Keys (North Key Largo to Conch Reef), Middle Keys (Alligator Reef to Sombrero Reef), Lower Keys (Looe Key to Smith Shoal), and Tortugas (Dry Tortugas to Tortugas Banks). In order to make valid comparisons between 2002 data and data from previous years, 1996-2000 data were recalculated using only data from stations that continued to be sampled after station reduction. This report presents data for those 117 stations (105 in Keys proper and 12 in Dry Tortugas). Dry Tortugas data are presented separately because sampling there was not initiated until 1999.

*Stony Coral Species Richness*
Sanctuary-wide from 1996 to 2002, the number of stony coral species declined at 74 stations (70%), increased at 21 stations (20%), and remained unchanged at 10 stations (10%) (Table 1). In 2002, the project documented a decline in stony coral species number in all habitat types. The offshore deep and patch reef stations had the greatest numbers of stony coral taxa, with 18 and 16 species, respectively. Hardbottom stations contained the fewest, averaging nine species per station.

**Table 1.** Number of stations with change in stony coral species richness by habitat type, 1996-2002.

| | **Patch** | | | **Shallow** | | | **Deep** | | | **Hardbottom** | | | **Total** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Years | No Change | Gain | Loss | No Change | Gain | Loss | No Change | Gain | Loss | No Change | Gain | Loss | No Change | Gain | Loss |
| 96vs97 | 5 | 3 | 21 | 6 | 24 | 9 | 4 | 11 | 11 | 1 | 6 | 4 | 16 | 44 | 45 |
| 97vs98 | 7 | 13 | 9 | 7 | 10 | 22 | 4 | 4 | 18 | 2 | 4 | 5 | 20 | 31 | 54 |
| 98vs99 | 7 | 8 | 14 | 6 | 6 | 27 | 5 | 4 | 17 | 1 | 0 | 10 | 19 | 18 | 68 |
| 99vs00 | 8 | 12 | 9 | 8 | 14 | 17 | 7 | 14 | 5 | 2 | 5 | 4 | 25 | 45 | 35 |
| 00vs01 | 5 | 11 | 13 | 9 | 17 | 13 | 3 | 9 | 14 | 1 | 7 | 3 | 18 | 44 | 43 |
| 01vs02 | 6 | 11 | 12 | 8 | 12 | 19 | 5 | 10 | 11 | 1 | 4 | 6 | 20 | 37 | 48 |
| 96vs02 | 5 | 3 | 21 | 1 | 10 | 28 | 2 | 5 | 19 | 2 | 3 | 6 | 10 | 21 | 74 |

Between 1996 and 2002, the number of stony coral species declined at 21 of 29 (72%) patch reef stations, increased at three stations, and remained unchanged at five stations (Table 1). For shallow reef stations, the number of stony coral species declined at 28 of 39 (72%), increased at 10 stations, and remained unchanged at one station. The number of stony coral species declined at 19 of 26 (73%) deep reef stations, increased at five stations, and remained unchanged at two stations. For hardbottom stations, the number of stony coral species declined at six of 11 (55%) stations, increased at three stations, and remained unchanged at two stations.

In the Upper Keys from 1996 to 2002, the number of stony coral species declined at 23 of 30 stations (77%), increased at two stations, and remained unchanged at five stations. In the Middle Keys, the number of stony coral species decreased in 20 of 29 stations (69%), increased at seven stations, and remained unchanged at two stations. In the Lower Keys, the number of stony coral species decreased at 31 of 46 stations (67%), increased at 12 stations, and remained unchanged at three stations. In the Dry Tortugas from 1999 to 2002, the number of stony coral species decreased at nine stations and increased at three stations.

Sanctuary-wide, the number of stations where *Acropora cervicornis* and *Scolymia lacera* were present decreased significantly ($\alpha = 0.05$) while the number of stations with *Colpophyllia natans*, *Madracis mirabilis, Porites porites, Siderastrea radians, Mycetophyllia ferox,* and *M. lamarckiana* decreased at the $\alpha = 0.1$ level. Only *Siderastrea siderea* was found at significantly more stations in 2001-2002 than in previous years.

*Stony Coral Condition*

Diseases were recorded as present or absent for each species at a station. In general, the number of stations documented as having diseased corals increased from 1996 to 2002 (Fig. 1). Overall, the number of stations containing diseased coral, the number of coral species with disease, and the different types of observed diseases all increased.

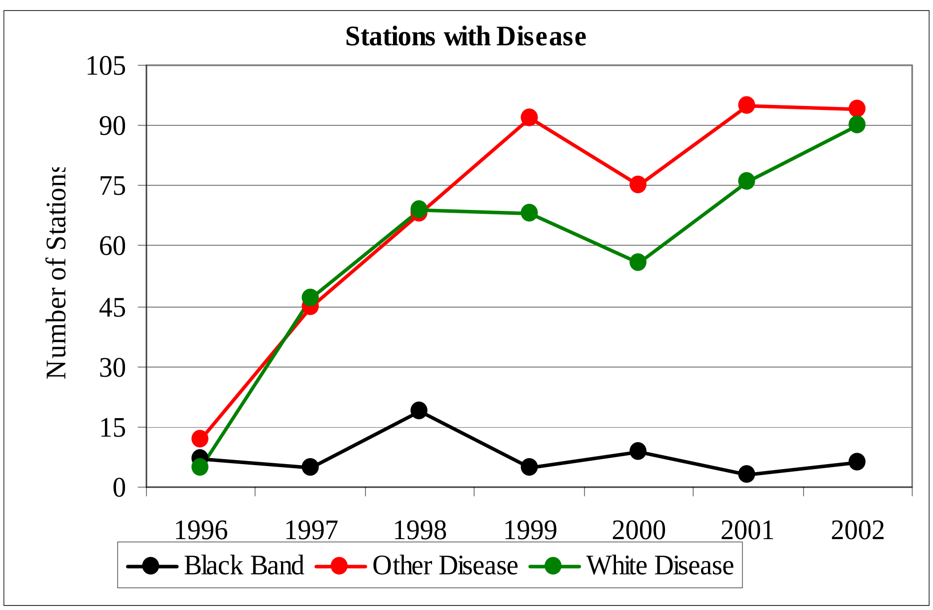


**Figure 1.** Number of stations with coral disease, 1996-2002.

As in previous sampling periods, black band disease was the least common of the disease categories recorded by the project. The number of stations with black band disease was highest in 1998 (19 of 105 stations). In all other years, black band disease was recorded at less than 10 stations. The species most commonly affected by black band disease were *Colpophyllia natans, Montastraea annularis, M. cavernosa*, and *Siderastrea siderea*.

The occurrence of "white disease" increased from five stations in 1996 to 90 stations in 2002 (Fig. 1). This increase was primarily driven by increases in white disease in *Montastraea annularis* complex, *Agaricia agaricites* complex, *Porites astreoides*, and *Siderastrea siderea* colonies. In 1996, *M. annularis* complex at all CREMP sites were free from white disease. By 2001, *M. annularis* complex at 32 stations were affected.

White disease was not found to have affected any *A. agaricites* colonies during 1996, but by 2001 white disease was observed on *A. agaricites* at 33 sites. This number had decreased to 27 stations in 2002. Incidence of white disease also increased in *P. astreoides* from zero stations in 1996, to six stations in 2001, and then 12 in 2002. The maximum value previously reported was 11 stations observed in 1997. Incidence of white disease in *S. siderea* increased from four stations in 2001 to 21 stations in 2002. The previous maximum occurrence for this species was 12 stations in 1997.

For adequate data for statistical testing, 2001 and 2002 disease data were pooled for comparison with 1996-2000 data. For the pooled 2001 and 2002 data, testing indicated that *Agaricia agaricites* complex, *Montastraea annularis* complex, *M. cavernosa*, *Siderastrea siderea*, and *Stephanocoenia michelinii* were affected by white disease at a significantly greater number of stations than the 1996-2000 data.

For the purpose of hypothesis testing, the "other disease" data for 2001-2002 were pooled and compared with the data from 1996-2000 to determine significant changes in the number of stations where each species was affected by "other disease." Tests indicated that 14 species had significant increases in the number of stations where "other disease" was detected. These species included: *Agaricia agaricites* complex, *Colpophyllia natans*, *Dichocoenia stokesii*, *Eusimilia fastigiata, Favia fragum*, *Meandrina meandrites*, *Millepora alcicornis, Millepora complanata, Montastraea cavernosa*, *Montastraea annularis* complex, *Porites astreoides, Porites porites*, *Siderastrea siderea*, and *Stephanocoenia michelinii*.

Pooled data for 2001-2002 were compared with pooled data for 1996-2000 to determine significant differences in the number of sites where bleaching affected each species. Bleaching affected *Agaricia agaricites* complex, *Montastraea annularis* complex, and *Montastraea cavernosa* at an increased number of sites during the 2001-2002 period.

*Stony Coral Cover*

Between 1996 and 2002, a 38% decline in stony coral cover was observed Sanctuary-wide (Fig. 2). This trend was confirmed by non-parametric hypothesis testing at the Sanctuary level. The decline in mean percent coral cover from 1997 to 1998 and from 1998 to 1999 was significant with a p-value of 0.03 or less for the Wilcoxon rank-sum test. Between 1997 and 1998 coral cover declined from 11.4% to 9.6%. The downward trend continued between 1998 and 1999 when coral cover declined from 9.6% to 7.4%. The changes observed from 1999 to 2002 were determined to be statistically non-significant. Sanctuary-wide coral cover has not changed significantly since 1999.

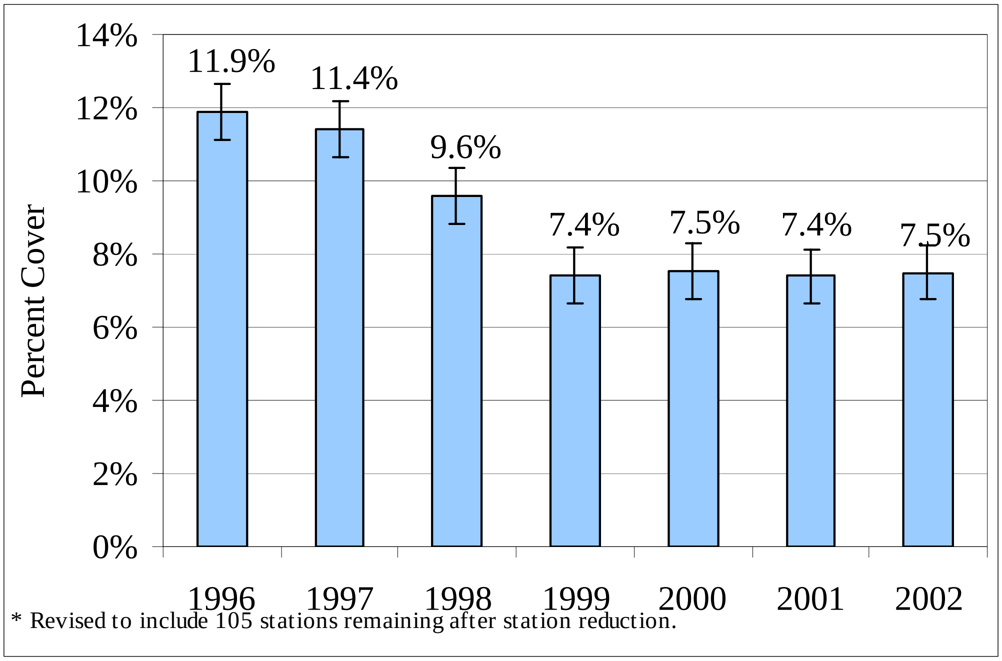


**Figure 2.** Mean percent stony coral cover Sanctuary-wide, 1996-2002.

At the regional and habitat levels, hypothesis testing compared 2002 coral cover data to pooled 1998-2001 data as well as pooled 1999-2001 data. Regionally, stony coral cover reflected patterns observed Sanctuary-wide. In all three geographical areas, a significant decrease in stony coral cover was observed between 1996 and 1998. Comparisons between 1998-2001 pooled data and 2002 data indicated significant decreases in stony coral cover within the Upper and Lower Keys regions. Comparisons between 1999-2001 pooled data and 2002 data detected no significant differences in stony coral cover for any region.

In the Upper Keys, 18 stations (64%) lost significant coral cover while two stations (7.1%) gained coral and eight stations (28.5%) remained unchanged (Fig. 3).

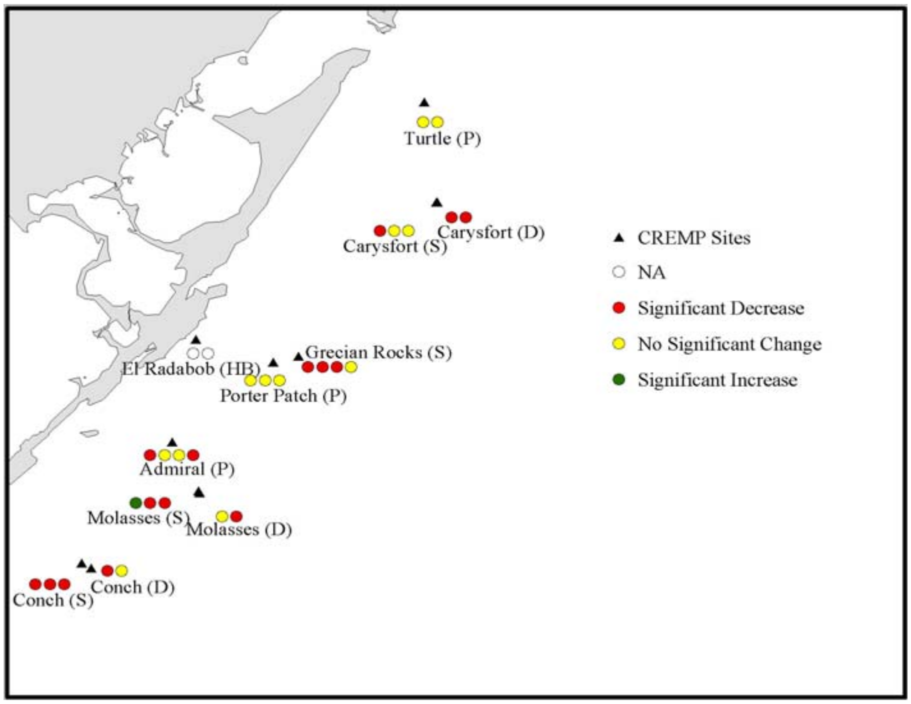


**Figure 3.** Distribution of significant change in stony coral cover at Upper Keys stations, 1996-2001 vs. 2002.

In the Middle Keys, significant coral cover was lost at 10 (34%) stations, no significant change was seen at 18 (62%) stations, and significant coral cover was gained at one station (Fig. 4).

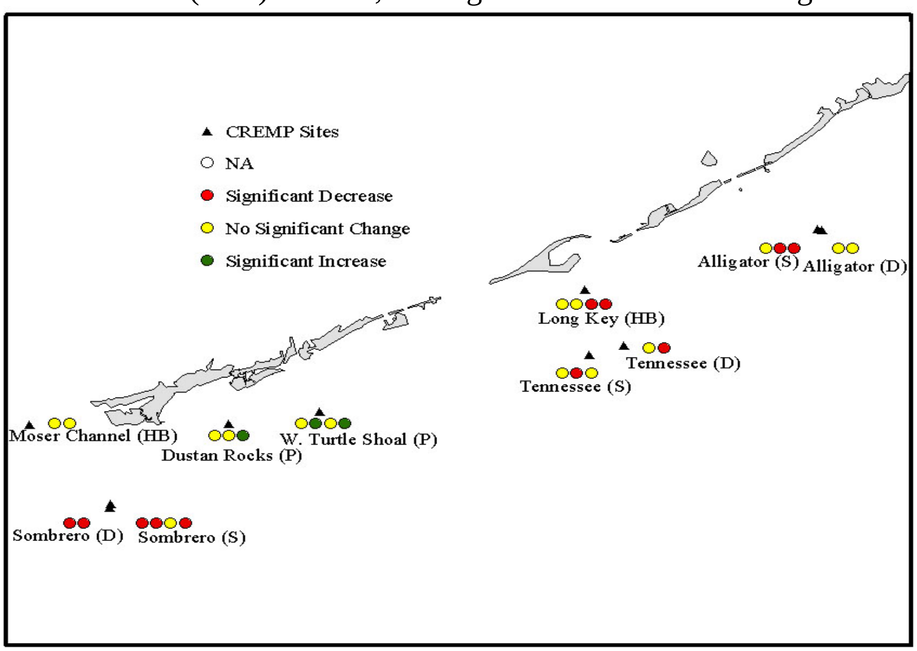


**Figure 4.** Distribution of significant change in stony coral cover at Middle Keys stations, 1996-2001 vs. 2002.

In the Lower Keys, significant coral cover was lost at 29 (63%) stations, no significant change was seen at 13 (28%) stations, and significant coral cover was gained at four stations (Fig. 5).

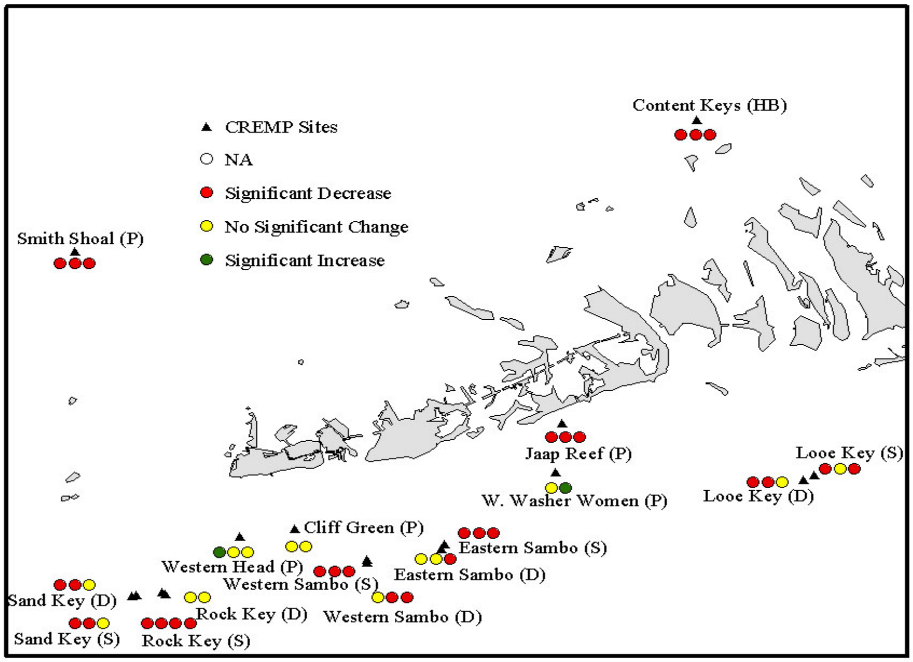


**Figure 5.** Distribution of significant change in stony coral cover at Lower Keys stations, 1996-2001 vs. 2002.

In the Dry Tortugas in 2002, significant coral cover was lost at eight stations, while no significant change was seen at four stations (Fig. 6).

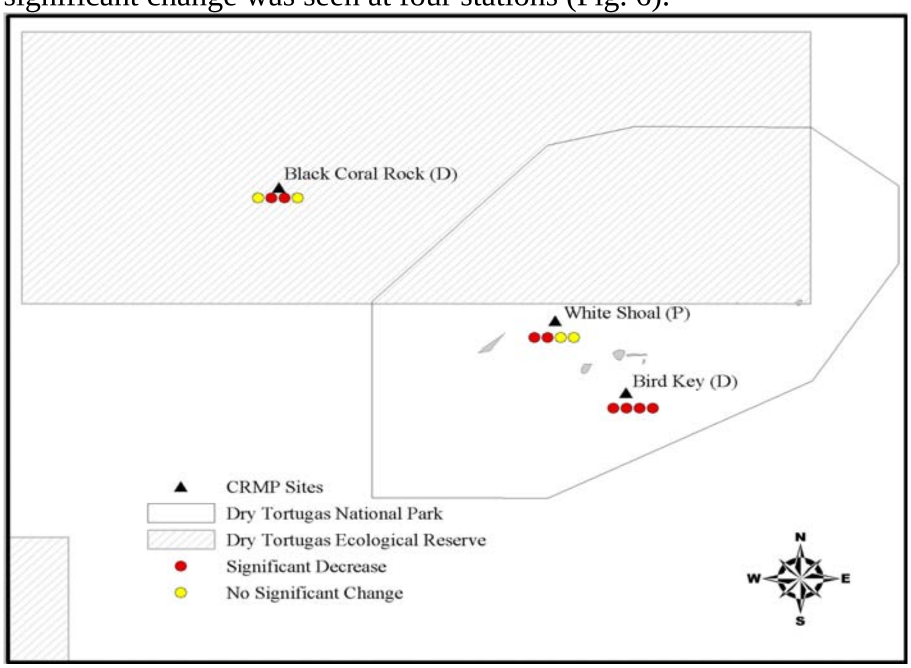


**Figure 6.** Distribution of significant change in stony coral cover at Dry Tortugas stations, 1999-2001 vs. 2002.

*Functional Group Cover*

Percent-cover data for functional groups in the geographic regions studied from 1996 to 2002 were analyzed. Functional groups included: stony corals, octocorals, zoanthids, sponges, macroalgae, seagrass, and substrate (rock, rubble, and sediments). In the Upper Keys from 2001-2002, macroalgae and octocoral cover increased slightly, while stony coral and sponge cover remained unchanged. The Lower Keys had a decrease in macroalgal cover and a slight increase in octocoral cover. Stony coral and sponge cover remained unchanged. The Middle Keys had a significant decrease in macroalgal cover and a significant increase in octocoral cover. All other components of the Middle Keys benthic community remained unchanged. Sanctuary-wide, in 2002, the benthic community at CREMP sites was composed of 66.8% substrate, 11.0% octocoral, 9.3% macroalgae, 7.5% stony coral, 2.5% sponge, 2.2% zoanthids, and 0.6% seagrass (Fig. 7).

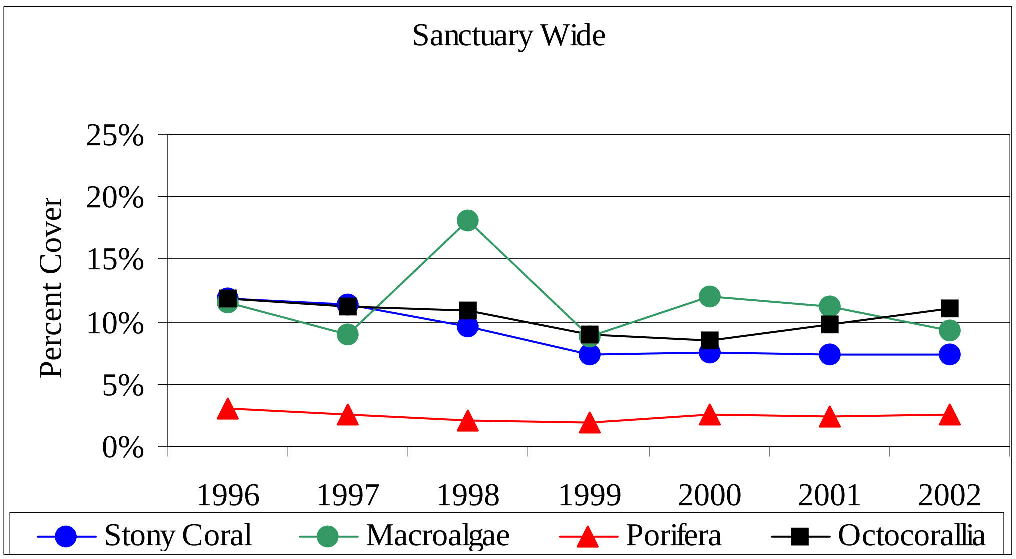


**Figure 7.** Mean percent cover of functional groups Sanctuary-wide, 1996-2002.

*Stony Coral Species Cover*

An understanding of the overall trend in stony coral cover can be gained by analyzing the changes in percent cover of the most common species. The six coral species with the greatest mean percent cover Sanctuary-wide in 1996 were *Montastraea annularis* (4.1%), *M. cavernosa* (1.4%), *Acropora palmata* (1.1%), *Siderastrea siderea* (1.0%), *Millepora complanata* (1.0%), and *Porites astreoides* (0.6%). *M. annularis* represented approximately 35% of the coral cover at CREMP stations in 1996. *M. annularis* decreased from 4.1% in 1996 to 2.7% in 2002 (a 34% reduction). *M. cavernosa* decreased from 1.4% in 1996 to 1.3% in 2002.

Although *Acropora palmata* (elkhorn coral) only occurs in offshore reef habitats sampled, and comprised only 1.1% of mean coral cover in 1996, it is well recognized as a primary framework species. Striking changes were documented for this species as well as *A. cervicornis* (staghorn coral) and *Millepora complanata*, the once-dominant, shallow reef, bladed fire coral. The mean percent cover of *A. palmata* decreased 91% from 1.1 in 1996 to 0.1 in 2002. Between 1996 and

2002 percent cover of *A. cervicornis* decreased 94%, from 0.20 to a barely detectable 0.01. Also, between 1996 and 2002 percent cover of *M. complanata* declined from 1% to 0.03%.

*Bioeroding Sponge Data*

In 2002, the mean area of clionid sponge cover was greatest at patch reef stations in the Lower Keys. In the Upper Keys, the number of clionid colonies decreased at all stations except deep ones. The greatest average number of colonies was seen at Upper Keys deep stations (109) followed by Lower Keys deep stations (53), and then Lower Keys patch reef stations (44). At Content Keys, the mean number of clionid colonies decreased from 35 in 2001 to zero in 2002. Likewise, at Smith Shoal the average number of clionid colonies decreased from 46 in 2001 to zero in 2002.

***Value-Added Station Sampling***

*Diseased Coral Survey (DCS)*

Overall, 323 diseased coral colonies of 22 different species were recorded at 18 stations in 2002. A total of 12 known coral diseases, and bleaching, affected coral colonies at CREMP value-added sites. Eleven species were most commonly affected by coral disease (Fig. 8).

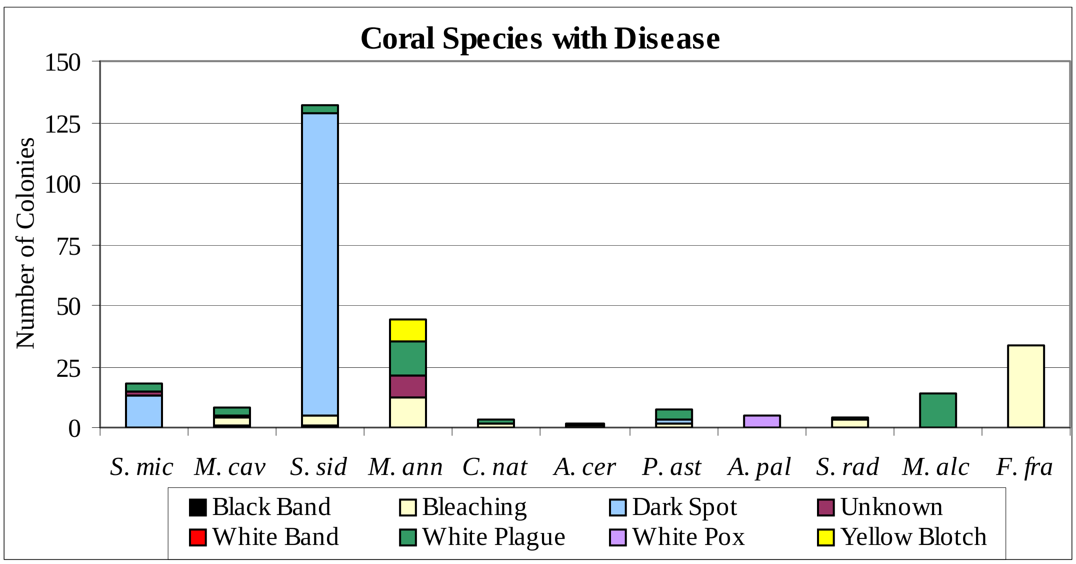


**Figure 8.** Number of colonies of selected coral species affected by disease within CREMP value-added sites during 2002.

*Siderastrea siderea* and *Montastraea annularis* were both affected by four diseases, while both *Stephanocoenia michelinii* and *M. cavernosa* were affected by three diseases each. All others were affected by two or fewer diseases. *Siderastrea siderea* was most commonly affected by what has been termed "dark spot" disease. It should be noted that although this malady was very common during the 2002 sampling period, "dark spot" disease had virtually disappeared from Middle Keys value-added stations by June 2003.

Black band, white plague, bleaching, and an unknown malady affected *M. annularis* complex colonies. In addition to *M. annularis* colonies, bleaching affected *M. cavernosa*, *S. siderea*, *S. radians*, *Colpophyllia natans*, *Porites astreoides*, and *Favia fragum*.

Preliminary review of the data indicated widespread existence of coral disease among nearly all coral species recorded at CREMP value-added stations. Cases of infection by all of the Caribbean coral diseases that can be distinguished underwater were identified.

*Stony Coral Population Dynamics*
Coral abundance was assessed at all 18 value-added stations (VAS). A wide range of community indices was calculated from VAS species data. Species richness ranged from seven to 26 while species diversity (H') ranged from 0.82 to 2.51. Abundance values also varied greatly, ranging from 18 colonies at Grecian Rocks station 2 to over 500 colonies at Cliff Green station 4.

The typical coral community at a CREMP value-added station contained 176 colonies representing 13 coral species. Twenty-two percent of coral colonies were in the 0-3 cm size class while 46% of colonies were 3-10 cm, 26% of colonies were 10-50 cm, and 10% were over 50 cm.

*Siderastrea* sp. had the greatest mean number of colonies in the 0-3 cm, 3-10 cm, and 10-50 cm size classes with 19.6, 16.4, and 9.1 colonies per station, respectively. Other common corals in the 3-10 cm size class included *M. alcicornis* (mean 13.52 colonies/station), *Stephanocoenia michelinii* (mean 13.27 colonies/station), and *Agaricia agaricites* (mean 3.27 colonies/station). In addition to *Siderastrea* sp., common corals in the 10-50 cm size class included *S. michelinii* (mean 7.35 colonies/station), *Porites astreoides* (mean 4.15 colonies/station), and *M. alcicornis* (mean 3.48 colonies/station). The most common coral species over 50 cm included *Montastraea annularis* (mean 3.04 colonies/station) *Colpophyllia natans* (mean 2.83 colonies/station), and *M. cavernosa* (mean 2.52 colonies/station).

***Discussion and Conclusions***
From its inception in 1996, the Coral Reef Evaluation and Monitoring Project (CREMP) has documented long-term changes in the status and trends of coral reefs throughout the 9,844-$km^2$ FKNMS. The data set produced from this monitoring effort has been, and will continue to be, an indispensable asset for sound resource management decisions. Between 1996 and 2002, the project reported a 38% reduction in stony coral cover sanctuary-wide. A steep decline in percent cover of stony corals was documented between 1997 and 1999. From 1999 to 2002, the percent cover of stony corals has remained essentially unchanged.

Hypothesis testing has revealed a significant loss in stony coral cover at 55% of project stations while only 7% showed a significant increase. By region, the Upper Keys experienced the greatest decline with significant loss in coral cover at 64% of stations, followed by the Lower Keys with loss at 63%, and the Middle Keys with a loss at 34% of stations. The greatest declines in coral cover occurred between 1996 and 1999. Coral cover declined from 11.9% in 1996 to 7.4% in 1999. Since 1999, percent cover at CREMP sites varied less than 0.1% per year. Statistical analysis has determined no significant difference in percent coral cover between 1999 and 2002, suggesting a halt in the decline of coral cover. This halt in coral decline has been recognized elsewhere as well. Wilkinson (2002) suggested that other reefs that showed severe declines in coral cover during the 1997-1998 bleaching event have shown slow to moderate signs of recovery.

Evidence such as the loss of hard corals, increased abundance of algae, and a dramatic increase in bleaching episodes and disease outbreaks are indications that coral reefs are deteriorating worldwide. The U.S. Coral Reef Task Force (http://coralreef.gov/threats.cfm) cites population increases, shoreline development, increased sediments in the water, trampling by tourists and divers, ship groundings, pollution, overfishing, and fishing with poisons and explosives that destroy coral habitat as some of the major anthropogenic threats to corals worldwide. These stresses act separately and in combination with natural factors such as hurricanes and disease to degrade reefs. Further, recent research supports a link between coral disease and anthropogenic stressors (Harvell et al. 1999; Porter et al. 1999; Shinn et al. 2000; Harvell et al. 2001; Porter et al. 2001; Patterson et al. 2002). These threats and others have contributed to an estimated 21% loss of coral reefs worldwide in 2000 (http://www.aims.gov.au/pages/research/coral-bleaching/scr2002/scr-00.html). The major emphasis of coral reef research worldwide is to identify the causes of coral decline and assess the synergistic impact of these causes on global, regional, and local scales.

On a regional scale, the 105 CREMP stations are downstream of much of the Caribbean basin, the Gulf of Mexico, the Everglades, and Florida Bay. The interaction between these upstream regimes and the Florida Keys varies in magnitude and on many time scales. On a local scale, the 105 CREMP stations are subdivided into four habitat types based on depth, distance from shore, and biotic character. Hardbottom, patch reefs, shallow offshore reefs, and deep offshore reefs each have characteristic sets of stony coral species and relative percent cover. As such, we expect coral reefs in the Florida Keys to respond to stress on multiple scales of space and time.

Since the beginning of the CREMP in 1996 a series of stress events, occurring in quick succession, appear to be responsible for the most recent declines in coral cover and species diversity. Global bleaching events in 1997 and 1998 were severe to moderate and resulted in increased stress, instigating morbidity and mortality in some cnidarian species. Elevated water temperatures were thought to be the cause of high mortality in *Millepora complanata* in Lower and Middle Keys offshore shallow reefs during this period. Although short lived, hurricanes can cause significant adverse affects to the coral reef community on regional and local scales. Gardner (2002) claimed that Florida reefs historically exhibited an average 6.5% loss in coral cover within one year of the occurrence of a hurricane. Hurricane Georges, which hit the Keys in 1998, resulted in coral losses of up to 44% at some locations (J. Dotten, pers. comm.).

The decline in coral cover observed on Florida reefs is similar to declines reported for reefs elsewhere in the Caribbean and Gulf of Mexico. Linton et al. (2002) reported that coral cover in the Bahamas has declined from 9.6% in 1994 to 4.0% in 2001. Bermuda reefs have displayed less precipitous declines with coral cover decreasing from 23% in 1993 to 18% in 2001. Coral cover in the Cayman Islands has also declined in recent years. Department of Environmental Protection and Conservation Unit data showed that Little Cayman reef corals declined from 23% in 1997 to 16% in 2001. On Grand Cayman, coral cover declined from 25% in 1997 to 15% in 2001 (Linton et al. 2002).

Reefs of the western Caribbean and the southern Gulf of Mexico have exhibited some of the greatest losses in coral cover in recent years. Major disturbances such as Hurricane Mitch in

1998 and Hurricanes Keith in 2000, Iris in 2001, and Isidore in 2002 have had major impacts on reefs along Belize, Honduras, and the Mexican Yucatan. Belize alone reportedly a loss of up to 75% coral cover on some reefs (Almanda-Villela et al. 2002). This series of hurricanes and the resultant flooding and sedimentation, and an increase in coral disease and bleaching, are expected to have long-term ecological consequences (Almanda-Villela et al. 2002).

The recovery of damaged corals appears to have slowed significantly in recent years. The impact of hurricanes on coral reefs is largely separate from the suite of anthropogenic stressors, but these anthropogenic stressors affect the recovery of reefs following physical disturbance events. The absence of post-hurricane recovery on CREMP stations is one of dozens of such observations in the Western Atlantic. A synthesis of coral monitoring data (Connell 1997) found no clear examples of reef recovery following disturbances of any kind. Connell (1997) did find 17 clear examples of coral decline in the Western Atlantic with no subsequent recovery. This sharply contrasts with reefs of the Indo-Pacific where Connell (1997) found 19 clear examples of coral decline with recovery, and 10 examples of decline with no recovery.

It is important to note that declines in coral cover and numbers of species are not necessarily a recent phenomenon and are likely the result of multiple, chronic and acute stressors acting at local, regional, and global scales over long periods. The shifting-baseline phenomenon emphasizes the importance of viewing recent CREMP results in the context of long-term dynamics in the Florida Keys.

For example, during the 1960s and 1970s, *Acropora* populations exhibited boom and bust dynamics. Populations would expand and occupy virtually all of the potential space on a reef such as Western Sambo. Spur-and-groove areas were densely populated with large and moderate-sized colonies of *Acropora palmata*, while the fore reef and back reef supported dense thickets of *Acropora cervicornis*. Populations that suffered extensive destruction from Hurricanes Donna and Betsy appeared to have recovered within five years.

In 1975 there were hectares of *A. cervicornis* within Dry Tortugas National Park, so much so that it was difficult to navigate in the area west of Loggerhead Key because *A. cervicornis* had grown upward to near sea level (Davis 1982). In late 1977 and early 1978, a severe winter cold front reduced the temperature to about 14°C and virtually all of the *A. cervicornis* was extirpated due to hypothermia. In 1981, a disease epidemic further reduced *A. cervicornis* populations to a minor component of the Florida Reef Tract (Jaap et al. 1989).

With reduced coral cover, high temperatures, and perhaps increased nutrients, marine algae expanded rapidly in the mid 1990s. Ideally, algal control occurs as the result of grazing by herbivores and storm events. However, throughout much of the Caribbean herbivore populations have been reduced due to disease and overfishing. The long-spined sea urchin *Diadema antillarum* is known to be an important algal grazer, but populations of this species have yet to recover from a Caribbean-wide die-off, which occurred in 1983. CREMP data show that macroalgae percent cover is more variable than other benthic biota. Despite the substantial reductions in herbivore populations, percent cover of macroalgae has not increased from 1996 to 2002. These results suggest that macroalgae are not limiting coral recovery of Keys reefs.

***Future Direction***

The health of coral reefs of the Florida Keys is dependent on the quality of water along the reef tract. Because of the sensitive nature of corals, even slight changes in water quality can prove stressful for the reef. The Florida Reef Tract is under constant threat from terrestrial impacts far from the reef habitat. Extensive agricultural areas and channelization in central and southern Florida may adversely affect the quality and quantity of water delivered to the Florida Everglades and Florida Bay. As water quality is impacted by changes in the volume of water delivered to Florida bay, reefs may decline in channel areas based on similar experiences in other locations (Tomascik and Sanders 1985; Richmond 1993; Furnas and Mitchell 2001; Geister 2001).

The Comprehensive Everglades Restoration Plan (CERP) aims to re-establish the historical flow of water through south Florida and Florida Bay. This massive project will inevitably alter biological communities and water quality in Florida Bay. Downstream of Florida Bay, the Florida Keys reef tract provides the last opportunity to quantify CERP-induced changes. Therefore, continued monitoring is crucial in order to document status and trends of coral reefs in the FKNMS. In addition to the ongoing monitoring, the CREMP will expand its sampling strategy to better understand causes of coral decline and effects of multiple stressors.

The CREMP will continue non-consumptive sampling at established sites from Key Largo to Tortugas Banks to document status and trends of the coral reef ecosystem. The project will continue to collect a comprehensive suite of indicators at nine of the established 40 sites. These additional indicators will consist of a Diseased Coral Survey (DCS), stony coral abundance survey, temperature measurements, rugosity measurements, and human enterovirus study. The DCS will quantify the abundance and distribution of different diseases. By following the fate of a select number of individual coral colonies, the CREMP will better understand coral community dynamics and mortality rates associated with individual stressors.

The comprehensive monitoring data set on stony coral cover, species richness, bleaching, disease, bioeroders, temperature, fate tracking, human enteroviruses, and abundance will assist in development of landscape-seascape program models to characterize physical, chemical, and biological stressors. Not only will these data assist managers in determining if the fully protected Tortugas Ecological Reserve and Sanctuary Preservation Areas (SPAs) are functioning to protect sensitive resources. They will also provide definitive feedback on downstream effects of the CERP.

This report is a product of the Fish and Wildlife Research Institute pursuant to U.S. EPA grant award number X-97468002-0, and NOAA grant award number NA16OP2554. The complete CREMP Executive Summary for 2002 may be found at:
http://www.floridamarine.org/features/view_article.asp?id=21400.

***Acknowledgments***
Lauri MacLaughlin, John Halas, Steve Baumgartner, Ben Haskell (FKNMS), Gary Collins, Fred McManus (EPA), Larry Pugh (NOAA/COP), Dale Griffin (USGS), Erin Lipp (UGA), Bob Zepp (NPS), Dry Tortugas National Park Staff. Statistical Consultants: Dr. Chris Tsokos, Dr. George Yanev.

***References***

Almada-Villela, P., M. McField, P. Kramer, P.R. Kramer, and E. Arias-Gonzalez. 2002. Status of coral reefs of Mesoamerica - Mexico, Belize, Guatemala, Honduras, Nicaragua and El Salvador. Pages 303-323 *in* C. Wilkinson (ed). Status of the coral reefs of the world: 2002. Global Coral Reef Monitoring Network, Australian Institute of Marine Science. http://www.aims.gov.au

Connell, J.H. 1997. Disturbance and recovery of coral assemblages. Coral Reefs 16: S101-113.

Davis, G.E. 1982. A century of change in coral distribution at Dry Tortugas: a comparison of reef maps from 1881-1976. Bull Mar. Sci. 32(2): 608-623.

Furnas, M., and A. Mitchell. 2001. Runoff of terrestrial sediment and nutrients into the Great Barrier Reef World Heritage Area. Pages 37-52 *in* E. Wolanski (ed). Oceanographic processes of coral reefs. Academic Press, Orlando, FL.

Gardner, T. 2002. Coral reefs of the tropical western Atlantic: A quantitative summary of recent temporal change and the relative importance of hurricane impacts. M.S. Thesis. University of East Anglia, Norwich. 77 pp + appendices.

Geister, J. 2001. Coral life and coral death in a recent Caribbean coral reef: a thirty-year record. Bull. Tohoku Univ. Mus. 1: 114-124.

Harvell, C.D., K. Kim, J.M. Burkholder, R.R. Colwell, P.R. Epstein, J. Grimes, E.E. Hofmann, E.K. Lipp, A.D.M.E. Osterhaus, R.M. Overstreet, J.W. Porter, G.W. Smith, and G.R. Vasta. 1999. Emerging marine diseases: Climate links and anthropogenic factors. Science 285: 1505-1510.

Harvell D., K. Kim, C. Quirolo, J. Weir, G. S. 2001. Coral bleaching and disease: Contributors to 1998 mass mortality in *Briareum asbestinum* (Octocorallia, Gorgonacea). Pages 97-104 *In* J. W. Porter (ed). The ecology and etiology of newly emerging marine diseases. Hydrobiologia pp 97-104.

Jaap, W.C., W.G. Lyons, P. Dustan, and J.C. Halas. 1989. Stony coral (Scleractinia and Milleporina) community structure at Bird Key Reef, F. Jefferson National Monument, Dry Tortugas, Florida. Fla. Mar. Res. Publ. 46. 31 pp.

Linton, D., R. Smith, P. Alcolado, C. Hanson, P. Edwards, R. Estrada, T. Fisher, R. Gomez Fermandez, F. Geraldes, C. McCoy, D. Vaughn, V. Voegeli, G. Warner, and J. Weiner. 2002. Status of coral reefs in the northern Caribbean and Atlantic Node of the GCRMN. Pages 277-302 *in* C. Wilkinson (ed). Status of the coral reefs of the world: 2002. Global Coral Reef Monitoring Network. Australian Institute of Marine Science. http://www.aims.gov.au

Patterson, K.L., J.W. Porter, K.B. Ritchie, S.W. Polson, E. Mueller, E.C. Peters, D.L. Santavy, and G.J. Smith. 2002. The etiology of white pox, a lethal disease of the Caribbean elkhorn coral, *Acropora palmata*. Proc. Nat. Acad. Sci. 99: 8725-8730.

Porter, J.W., P. Dustan, W.C. Jaap, K.L. Patterson, V. Kosmynin, O.W. Meier, M.E. Patterson, and M. Parsons. 2001. Patterns of spread of coral disease in the Florida Keys. Pages 1-24 *In* J.W. Porter (ed). The ecology and etiology of newly emerging marine diseases. Hydrobiologia, pp 1-24.

Porter, J.W., S.K. Lewis, and K.G. Porter. 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. Limnol. Oceanogr. 44: 941-949.

Richmond, R.H. 1993. Coral Reefs: present problems and future concerns resulting from anthropogenic disturbance. Amer. Zool. 33: 524-536.

Shinn, E.A., G.W. Smith, J.M. Prospero, P. Betzer, M.L. Hayes, V. Garrison, and R.T. Barber. 2000. African dust and the demise of Caribbean coral reefs. Geophys. Res. Lett. 27: 3029-3032.

Tomascik, T., and F. Sander. 1985. Effects of eutrophication on reef building corals. Mar. Biol. 87: 143-155.

Wilkinson, C. (ed). 2002. Status of the coral reefs of the world: 2002. Global Coral Reef Monitoring Network, Australian Institute of Marine Science. http://www.aims.gov.au